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ABSTRACT

Understanding science and technology issues requires a number of spatial abilities in order to comprehend the three-dimensional structure of systems. Adequate spatial abilities have long been identified as a necessary mental tool for understanding science and technology phenomena. Multimedia technology has opened the door for a large variety of options that significantly enhance intelligent computer aided instruction (ICAI) in general, and students' spatial aptitude in particular. A number of multimedia-supported visualization techniques have been utilized in a studyware of human physiology. This paper presents these techniques using the brain module as a case in point. All modules were developed using HyperCard on Macintosh computers. Each module can be used separately or in conjunction with other modules. The techniques for the brain module include looking inside the brain, involving the student in exposing brain parts, viewing the brain from different aspects and linking structure with function. A learning path map prevents students from getting lost in the web of possible hypermedia paths. Students electing to deepen spatial ability can do so by a series of moving pictures, appearing one after the other, creating the illusion of a rotating brain. Student evaluation is done through voluntary quizzes and mandatory tests. The mandatory test must be completed before a student can advance to the next topic. Five figures illustrate studyware screens. (Author/MAS)

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Multimedia-Supported Intelligent Computer Assisted Instruction: a Spatial Journey into the Brain

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Abstract: Understanding science and technology issues requires primarily a number of spatial abilities to comprehend the 3-dimensional structure of systems. Adequate spatial abilities have long been identified as a necessary mental tool for understanding science and technology phenomena. Multimedia technology has opened the door for a large variety of options that significantly enhance Intelligent Computer Aided Instruction (ICAI) in general and students' spatial aptitude in particular. We have been utilizing a number of multimedia-supported visualization techniques in a studyware of human physiology. This paper presents these techniques using the Brain module as a case in point. The techniques include looking inside the brain, involving the student in exposing brain parts, viewing the brain from different aspects and linking structure with function.

Theoretical foundations of the teaching/learning process on one hand and recent advances in multimedia technology on the other hand, have made possible the creation of a learning environment that benefits from both. This is the basis for the analysis of an hyper-environment – shell – for Intelligent Computer Assisted Instruction (ICAI) development. Within this ICAI shell, science and technology studyware can be developed most efficiently, using state-of-the-art technology and science education methods (Dori, Dori & Yochim, 1992). The division of the learning environment and science or technology domain of study, into two components of a studyware opens the way for the development of a generic framework that supports studyware authoring. Such a framework, or "shell," should enable the expert team, charged with the curriculum development, to concentrate on a sound presentation and teaching of the subject matter. At the same time, the shell is supposed to take care of putting the subject matter in the right educational context, relieving the developers from the burden of low level programming, such as graphic user interface and repetitive tasks.

We have adopted this approach in the development of the *Human Physiology* studyware. The idea of standardizing elements in the software under development, which eventually has turned into a framework for a shell definition, has evolved as the individual modules were being developed. The first module was *The Endocrine System* (Yochim & Dori 1993A). It already contained many of the principal elements that were later reused and improved in the subsequent modules:*The Nervous System* (Yochim & Dori 1993B) and *The Digestive System* (Yochim & Dori 1993C), but several important features were added. These include incorporating test barriers consisting of randomly selected sets of questions, as well as navigation and orientation aids.

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Multimedia as a Means of Improving Spatial Ability

Multimedia is a key component of intelligent computer assisted instruction. It is a superb tool that enables the ICAI module domain expert developer to express and convey his/her knowledge about systems and their behavior. Grasping how systems' components interact with each other in both the spatial and temporal domains is the key to understanding science and technology issues.

Spatial understanding of complex structures, as the ones that occur in biological systems, is an important cognitive ability, which involves 3-dimensional thinking. According to McGee (1979), spatial ability is the ability to mentally juxtapose, orient, manipulate, rotate, twist and invert pictorially presented objects. Linn & Peterson (1985) subdivide spatial abilities into three categories: (1) Spatial perception: the ability to determine spatial relationship with respect to the orientation of one's own body. (2) Mental rotation: the ability to mentally rotate a two- or three-dimensional figure rapidly and accurately. (3) Spatial visualization: a problem solving ability of tasks involving multi-stage manipulations of spatially presented information. A significant number of studies (e.g., Small & Morton, 1983; Lord, 1985; and Ben Haim, Lappan & Houang, 1988) have shown that spatial skills can be improved through learning experiences. Linn & Peterson (1985) and Lord (1987) have found gender differences in spatial abilities which can be improved by meaningful interventions. Differences in spatial abilities have also been found between science majors and non-science, liberal arts counterparts, favoring science majors.

These findings point to the significance of spatial aptitude to all science disciplines. Science educators should therefore construct and reinforce spatial thinking and mental formation and manipulations of images in their students. This way they can reach their true potentials and be more scientifically oriented. Multimedia is an ideal tool for materializing these recommendations in science in general and for human physiology systems in particular. The integration of text with graphics has created a host of new opportunities of explaining and demonstrating complex systems' structures and their relation to functions.

Looking Inside the Brain

We have taken advantage of the great variety of options offered by multimedia in the *Human Physiology* studyware discussed above. It comprises a series of modules for teaching and exploring different topics in human physiology. All the modules were developed using HyperCard on Macintosh computers. Each module can be used separately or in conjunction with the other modules, thus can be considered a separate volume – electronic book – in an electronic encyclopedia on human physiology. In this paper, we elected to concentrate on the Brain module as a case in point. From the opening screen it is possible to access directly different subjects included in the module without the need to go sequentially through them, thereby enabling quick access to any desired topic, assisted by on-line help. An even more elaborate access and navigation mechanism is provided by the map of Learning Path, shown in Figure 1. It is a tree structure of the three different levels of detail depth, and cognitive aptitude that the studyware encompasses.

The first level of the Brain module has three topics: Introduction, Sensory Input and Motor Output, and Processing the Signals. Each topic is accessible by clicking the mouse at the name of the topic. Each of the sub-topics in the second level of complexity is recorded next to a "radio button" pointed to by a gray arrow, such as The Somatic Senses in topic B. The sub-topics, too, are accessible by clicking at their buttons. Finally, the most detailed information appear in the subsections, which are the "leaves" of the subject tree hierarchy, and they are directly accessible as well. Taste, Vision, and Audition are examples of such "leaves" in the Somatic Senses sub-topic.

The problem of "getting lost" in the web of possible paths of complex multimedia documents of the order of magnitude of *Human Physiology* is well known to both users and developers of such environments. The Learning Path (LP) map is an invaluable tool for both orientation and navigation throughout the study session. Each card (screen) in the module is equipped with the button "Where Am I?," which can be seen in each one of the following screen images. This button, when clicked, invokes this map and causes the appropriate topic, from which the student asked where he was, to blink repeatedly, until the

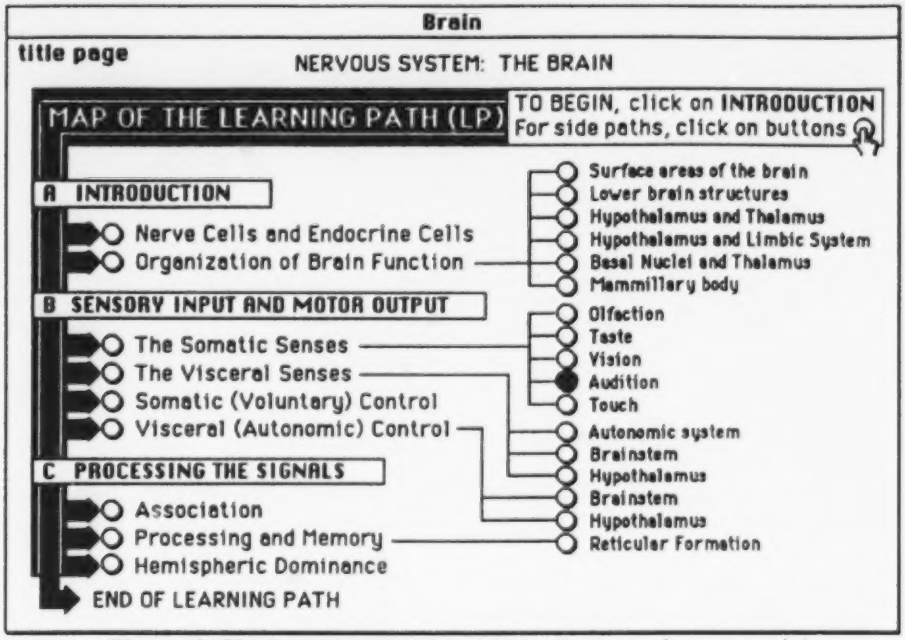

Figure 1. *The Learning Path map of the Brain studyware module*

screen is clicked again somewhere. From the map, the student can either return to where he came from or proceed to another topic. In Figure 1, for example, the student has come from the Audition leaf, which, in the actual study unit, is blinking.

Fostering Mastery Learning Through Exposure of Brain Parts

Following a number of introductory cards, the student is already asked to actively participate in the process of exposing the brain parts. Each boldface word in the text of Figure 2, (such as **brainstem**, **hypothalamus**, and **limbic system**) when pointed to by the mouse (even without clicking) causes the exact location of the corresponding brain part to be marked on the brain drawn to the right. Simulating a brain dissection, which in reality is done only by medical students, if it is at all feasible, with multimedia becomes an easy task that can be performed repeatedly back and forth with no extra cost or effort. By clicking at the left hemisphere of the brain, as the student is instructed to do in another screen, the left hemisphere is removed, and using a visual effect built into HyperCard, the picture is dissolved into a new screen, exposing the brain's inner components.

Having exposed the inner brain's parts, by moving the cursor around the various parts, the name of each part shows up as the cursor enters its area and disappears as the cursor exits it. This is implemented by setting buttons or fields that respond to an "`on mouseEnter`" HyperTalk command. By providing this option, the student has as much time as he or she needs to explore the newly exposed parts. Moreover, by clicking on the back radio button, it is possible to return back to the first card and repeat the simulated hemisphere removal over and over again. This pattern of providing for the iteration of almost any significant visual operation, is used throughout the studyware. This mastery learning principle enables the student to iterate any dissection, rotation, or animation sequence, until he or she is satisfied with the level of spatial understanding of the 3-D structure of the parts being displayed and manipulated.

Animation: Viewing the Brain from Different Aspects

A student electing to deepen his spatial abilities can do so by viewing the brain structure by a series of moving pictures. The pictures appearing one after the other are arranged as a

movie, creating the illusion of a rotating brain that is viewed by the spectator from all the important angles. Four of the 12 pictures of this brain movie are presented in Figure 3. This movie goes on repeatedly until the student deliberately stops it.

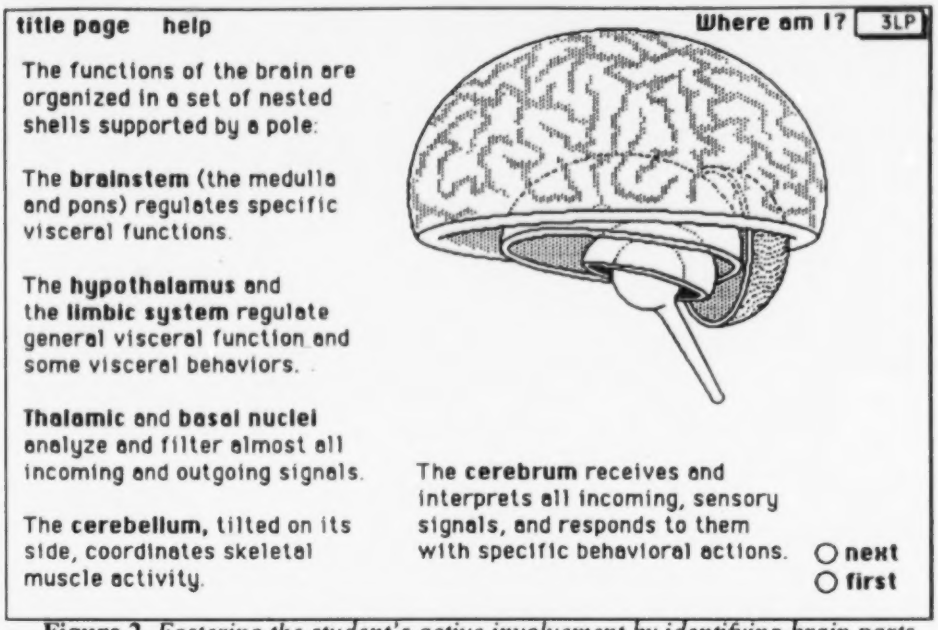
title page help
Where am I? 3LP
The functions of the brain are organized in a set of nested shells supported by a pole.
The brainstem (the medulla and pons) regulates specific visceral functions.
The hypothalamus and the limbic system regulate general visceral function and some visceral behaviors.
Thalamic and basal nuclei analyze and filter almost all incoming and outgoing signals.
The cerebellum, tilted on its side, coordinates skeletal muscle activity.
The cerebrum receives and interprets all incoming, sensory signals, and responds to them with specific behavioral actions.
next
first

Figure 2. *Fostering the student's active involvement by identifying brain parts*

Movies of this nature enhance the first two of the three spatial abilities discussed above. Spatial perception, which is the ability to determine spatial relationship with respect to the orientation of one's own body, is obtained by the different viewing angles. Mental rotation, i.e., the ability to mentally rotate a two- or three-dimensional figure, is experienced by the student watching the brain movie. The student may, at any point along the movie, "freeze" it by simply moving the cursor away from the bottom area of the movie display area, and "unfreeze" it by moving the cursor to the same area. As long as the cursor is there and the mouse rests, the movie repeats itself. This utmost flexibility in movie control is accountable for obtaining high spatial understanding, as the student can stop the movie and advance it at any desired point to examine details that seem not to be clear enough.

Linking Structure with Function: the Barrier Test

The studyware offers the student a number of options to evaluate himself/herself. This is done through voluntary quizzes (Dori & Yochim, 1990) and mandatory tests. Before the student is allowed to advance from the introduction to the second topic, Sensory Input and Motor Output, the Brain module asks the student to try to passe a mandatory barrier test. The test is composed of a set of five questions chosen randomly by the program, ensuring that the same test is not administered to the same student more than once. This is done by keeping a record of the tests given to each student, who is required to identify himself/herself before the test is presented.

Figure 4 is a sample of a barrier test of the Organization and Brain Function sub-topic. It is aimed at testing the extent of meaningful learning the student obtained. The five problems presented in the test are covered by a field saying **Click here for question i**, with i = 1,...5. In Figure 4, the student has already answered questions 1, 2, and 4. He scored 61% in question 2 and lower than a passing grade (set at 55%) in question 4. The low achievement in question 4 is responded by the studyware's advise to review the specific sub-topic *Surface Brain Structures*, as the question deals with this sub-topic. Question 5 has just been exposed but not yet answered. The questions are oriented towards several

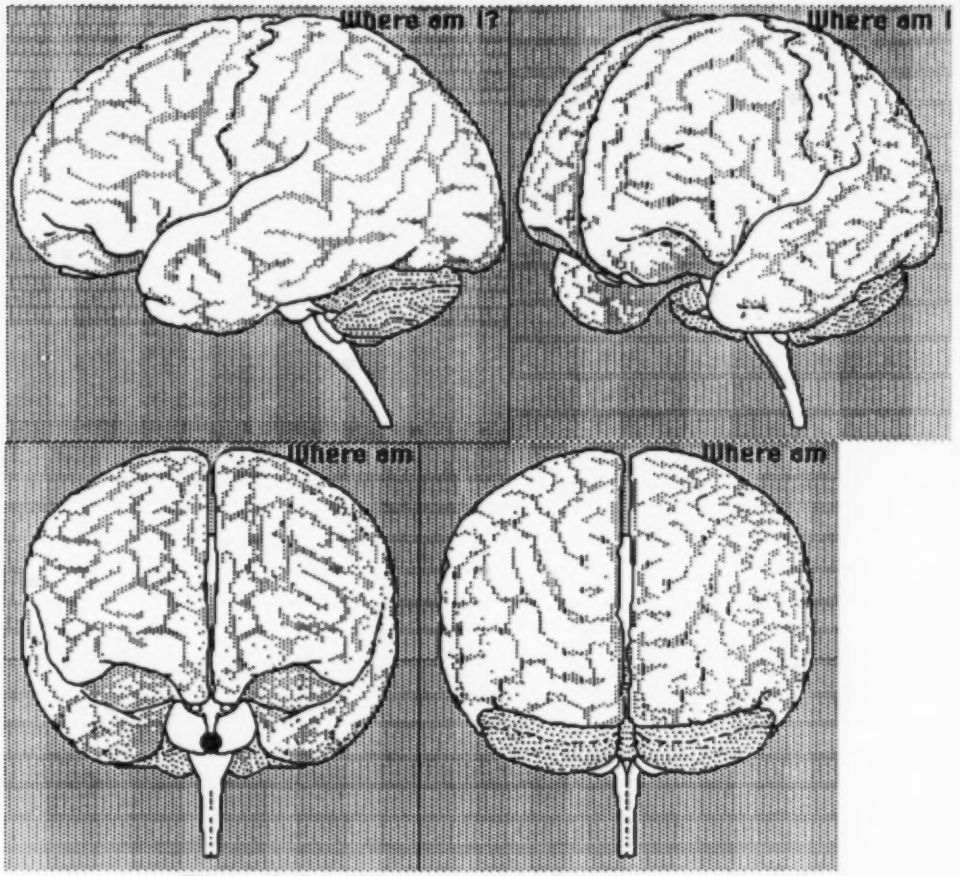

Figure 3. *Sample pictures of the brain structure movie*

cognitive levels. Question 1 requires the identification of a single part (basal nuclei). Question 2 asks to identify three parts in the brain structure: hypothalamus, mammillary body, and fornix. Question 4 concerns understanding of the spatial brain structure: it calls for pointing at a major subdivision of the cerebrum. Correctly answering this requires that the student understands that the cerebrum consists of several major parts and there are four points that need to be pointed at. This question reflects the level of the third spatial ability, spatial visualization. It involves problem solving of tasks with manipulations of spatially presented information. Questions 3 and 5 requires comprehension of the relation between structure and function. Higher levels of problem solving abilities appear in the barrier tests before entering the third topic - Processing the Signals. When the student is done with answering the five questions, clicking on the **grade** button sends a message to the program to calculate the grade. A new screen is then opened, telling the student his/her grade. Having passed the test, the student is able to advance to the next topic. Otherwise, a list of sub-topics that need be reviewed shows up below the grade with buttons leading directly to each sub-topic. As can be seen, the system monitors the students' performance as expressed by their responses to problems posed to them and reacts accordingly. This is a first step in imitating the role of an exemplary teacher, who is expected not only to grade the test but, more importantly, provide the right directions for the appropriate remedial learning activity.

Summary

We have presented a multimedia-based studyware application, which serves as an evolving model for an ICAI shell. With the resulting study modules, students can engage in

enjoyable active learning and enhance their spatial abilities while the system monitors their responses and reacts accordingly.

The enabling technology of multimedia suits the non-linear nature of knowledge, which is so difficult to convey by books. The Brain module of the *Human Physiology* studyware has been presented as a case in point. It is our belief that the concepts and architecture proposed in this work will be further developed and take advantage of the synergy emanating from the fusion of modern educational theories and the opportunities offered by multimedia technology.

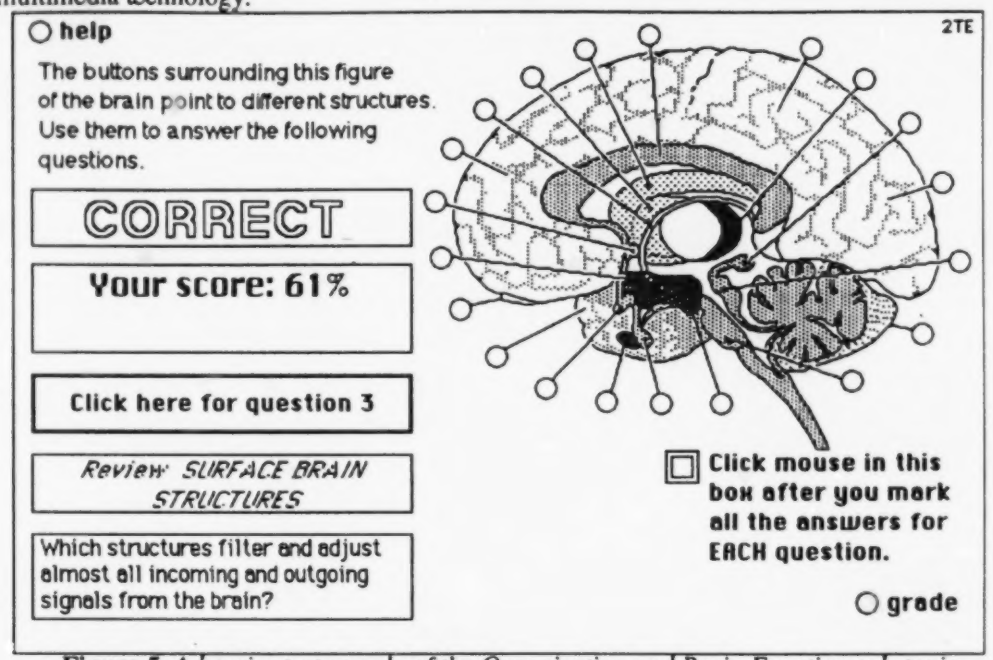
help
2TE
The buttons surrounding this figure of the brain point to different structures. Use them to answer the following questions.
CORRECT
Your score: 61%
Click here for question 3
Review: SURFACE BRAIN STRUCTURES
Which structures filter and adjust almost all incoming and outgoing signals from the brain?
Click mouse in this box after you mark all the answers for EACH question.
grade

Figure 5. *A barrier test sample of the Organization and Brain Function sub-topic*

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A– *Nervous System: The Brain;* B– *The Endocrine System;* C– *The Digestive System.*